ENDOR STUDIES OF RADIATION-PRODUCED

TRAPPED ELECTRONS AND RADICALS IN

DISORDERED SYSTEMS AND

RADICAL-MATRIX INTERACTIONS IN

POLYMERS AND ON SURFACES

FINAL REPORT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

ENDOR has been applied to radiation-produced trapped electrons and radicals in glassy and polymeric matrices. The temperature dependance of peroxy radical spectra has been analyzed in terms of specific motional mechanisms. Abstracts of 20 publications and titles of 40 scientific talks on these topics are given. The emphasis has been to develop new methods for the application of ENDOR to disordered systems and for the analysis of peroxy radical spectra vs temperature.

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This Final Report covers the period November 1, 1975 to February 28, 1982.

1. <u>Brief Progress Summary</u>

During this period we have developed matrix ENDOR (electron nuclear double resonance) for the study of radicals in disordered systems including polymers and have demonstrated the utility of g-anisotropy averaging of peroxy radicals for the study of specific motional mechanisms in disordered systems.

A generalized matrix ENDOR lineshape model has been developed using a density matrix formalism. The model includes the radiofrequency and microwave field intensities as well as different relaxation paths explicitly. This model has been tested against the small amount of single crystal data that exist for matrix ENDOR responses, namely for the methyl radical in γ-irradiated lithium acetate dihydrate and for the protonated carboxyllic anion radical in γ-irradiated L-alanine. In general, the theoretical simulations agree satisfactorily with the experimental lineshape, microwave magnetic field dependence and radiofrequency magnetic field dependence. It is further deduced that an angularly independent nuclear relaxation mechanism dominates the matrix ENDOR response. Further investigation has shown that this angularly independent relaxation rate can be identified with nuclear spin diffusion. This now gives a fairly complete understanding of the matrix ENDOR response.

Matrix ENDOR and ESR have been used to study several γ-irradiated substituted methacrylate lithographic polymers. Mid-chain and end chain radicals are found and ENDOR is used to assess the compactness of the radiation degradation region and hence the potential resolution of the resist.

A theoretical study based on a semicontinuum potential model has also been carried out on ENDOR studies of trapped electrons in hydroxy sugar crystals. The results suggest that dipole rearrangement occurs during electron trapping even at 4 K.

The use of peroxy radicals for motional studies was first developed with the triphenylmethylperoxy radical in γ-irradiated polycrystalline triphenylacetic acid. Temperature dependent ESR studies at 35 GHz gave reversible complex spectra at intermediate temperatures which aroused our interest. It was found possible to stimulate the spectra over the entire temperature range with the modified Bloch equations for motional processes for a specific motional model, 120° jumps of the peroxy group about the C-O bond. However, the most significant finding was the sensitivity of the spectral simulations to the particular motional model assumed. This provides the first spin probe with good specificity for identifying particular motional mechanisms.

In further development of this motional probe we have shown that a similar formalism can be used to interpret the spectra of $(CO_2-O_2)^-$ on an MgO surface in terms of a specific cubic jump motional model of the O-O group. This may reflect the cubic symmetry of the MgO surface and indicates a new method for studying motional processes of oxygen species on surfaces.

Also, the peroxy radical motional probe has been shown to be effective in polymeric systems by a study of peroxy polyethylene in urea-polyethylene complexes. The most recent work explores the applicability of peroxy radical probes to polytetrafluoroethylene, methacrylate polymers, polypropylene, poly(vinylidene fluoride), urea-n-alkane adducts and poly(vinyl alcohol). This comprehensive series of investigations demonstrates the effectiveness of using the peroxy probe for determining specific motional mechanisms in polymers. The general types of motion as a function of position on the polymer chain and as a function of side chain substituent polarity and size have been largely delineated.

2. Abstracts of Publications

1. Electron-Proton Distance Changes During Solvation of Electrons in 3-Methylhexane and Other Organic Glasses by Matrix ENDOR and Second Moment EPR Lineshape Analyses, Ding-Ping Lin and Larry Kevan, Chem. Phys. Lett., 40, 517 (1976).

Matrix proton ENDOR signals have been measured for stabilized electrons produced by irradiation at 4K and at 77K in 3-methylhexane glass. The matrix proton ENDOR linewidths are smaller when irradiation is carried out at 77K. This difference is analyzed to show a 0.15Å change in the average electron proton distance as the electron produced at 4K is solvated by warming to 77K. Similar distance changes have been deduced from a second moment EPR lineshape analysis for electrons in several organic glasses for which the proton hyperfine interaction is mainly dipolar.

2. Solution ENDOR of the Tri-t-butyl Phenoxy Radical: Nuclear Relaxation Mechanisms, P.A. Narayana and Larry Kevan, J. Magn. Resonance, 24, 137 (1976).

ENDOR studies of the tri-t-butyl phenoxy radical in mineral oil in the temperature range 300-350K have been carried out to assess the nuclear relaxation mechanisms. The temperature dependence of the ring α-proton intensities differs markedly from that of the t-butyl protons. The results are analyzed in terms of a multi-level model system containing two equivalent α-protons and three equivalent β-protons employing the full theory developed by Freed and his collaborators including coherence effects. The analysis indicates that the electron nuclear dipolar (END) mechanism is

dominant for the ring α-protons and that the α- and β-protons
have distinctly different behavior vs temperature. To the
extent that the nine t-butyl protons can be approximated by
three methyl protons the results suggest that both END and
modulation of isotropic hyperfine coupling mechanisms provide
comparably important pathways for nuclear relaxation of such
protons.

3. Matrix ENDOR Studies of the Orientation of Amine Molecules Around Trapped
Electrons in γ-Irradiated Amine Glasses, F.Q.H. Ngo, S. Noda and L. Kevan,
Proceedings of Fourth International Symposium on Radiation Chemistry, P.
Hedvig and R. Schiller, eds., Akademiai Kaido, Budapest, 1977, pp. 951-962.

Trapped, solvated electrons in primary, secondary and tertiary
amine glasses have been studied by EPR and ENDOR to deduce a-
spects of the geometrical structure of the amines around the
electrons. NH deuteration experiments show no effect on the
EPR and ENDOR linewidths of trapped electrons in primary and
secondary amines and indicate that the alkyl protons are closer
than the NH protons to the electron. The trapped electron EPR
linewidths are larger in primary and secondary amines ($\sim$7G) than
in tertiary amines ($\sim$4G) which suggests a small contact hyperfine
coupling; this is supported by ENDOR data. In tertiary amines EPR
and ENDOR results on trapped electrons suggest that the proton in-
teraction is purely dipolar and that the closest protons are $\sim$3.4Å
from the electron. In the more polar primary and secondary amines
the small proton contact interaction suggests that the closest pro-
tons are <3.4Å from the electron.

4. ENDOR and ELDOR of Paramagnetic Species in Disordered Matrices, L. Kevan
    and P.A. Narayana, Chapter IV, in Multiple Electron Resonance Spectro-
    scopy, M. Dorio and J. Freed, eds., Plenum Press, New York, 1979, pp. 229-259.

    The applications of electron nuclear double resonance (ENDOR)

    and electron-electron double resonance (ELDOR) to radicals trapped

    in disordered matrices such as glasses and polycrystals are dis-

    cussed. In polycrystalline matrices single-crystalline ENDOR

    spectra can be obtained in certain systems. In glassy matrices

    only a matrix ENDOR Line is usually seen. A simple model for

    matrix ENDOR has given much semiquantitative information about

    the delocalization of the unpaired electron wavefunction. An im-

    proved model is currently being developed which appears to give a

    more quantitative picture of the matrix ENDOR response. ELDOR has

    been used to evaluate the noninteracting spin packet model of in-

    homogeneously broadened lines and to directly study cross relaxation

    between two different radicals in glassy matrices.

5. An Improved Lineshape Model for the Matrix ENDOR Response in Disordered
    Systems, P.A. Narayana, M. K. Bowman, D. Becker, L. Kevan and R.N. Schwartz,
    J. Chem. Phys., 67, 1990 (1977).

    An improved lineshape model for the matrix ENDOR reponse near the

    free-nucleus precession frequency in disordered systems is developed

    and applied to a spin system with S=1/2 and I=1/2 using a density

    matrix formalism. The model includes the radiofrequency and micro-

    wave field intensities as well as different spin relaxation paths

    explicity. Application of this model to trapped electrons in 2-

    methyltetrahydrofuran glass gives geometrical and magnetic data

    which are in excellent agreement with existing data from electron

    spin echo experiments. The effects of the various parameters in the

    theory of the matrix ENDOR lineshape are discussed.

6. Matrix ENDOR Studies of the Proton Environment of the Radical in Natural and Solvent-Refined Coal, S. Schlick, P.A. Narayana and Larry Kevan, J. Am. Chem. Soc., 100, 3322 (1978).

The radical in natural and solvent refined coal (SRC) has been studied by electron nuclear double resonance (ENDOR) between room temperature and 30 K as a function of the microwave and radiofrequency field intensities. The observation of a strong proton matrix ENDOR line show interaction of the coal radical with nearby protons. By simulating the matrix ENDOR line with a new, improved lineshape model we conclude that the closest protons are situated at 2.6 ± 0.2 Å from the unpaired electron of the coal radical and that the average isotropic hyperfine coupling of these closest protons is 1.3 ± 0.3 MHz. The experimental variation of the matrix ENDOR lineshape and intensity with microwave and radiofrequency field intensity is simulated well at lower microwave powers by the improved ENDOR lineshape model although deviations occur at higher microwave power. The differences of the ENDOR signals for natural and solvent refined coal are explained in terms of different electron and nuclear spin-lattice relaxation times, in line with the rather well established assumption that the structures in both coals are similar.

7. Test of Improved Matrix Endor Lineshape Model Based on Single Crystal Data,
   L. Kevan, P. A. Narayana, K. Toriyama and M. Iwasaki, Magnetic Resonance
   and Related Phemomena, Proc. XXth Congress Ampese-Tallinn, USSR; E. Kundla,
   E. Lippman and T. Salurere, eds., Springer-Verlag, Berlin, 1979, p. 221.

   A new general matrix ENDOR lineshape model is tested against

   data on the CH_3 in γ-irradiated $LiCH\ COO\cdot2H_2O$. The theoretical

   simulations agree satisfactorily with the experimental lineshape,

   microwave magnetic field dependence, H_1, radiofrequency magnetic

   field dependence, H_2 and angular dependence of single crystal

   ENDOR line intensities.

8. General Matrix ENDOR Lineshape Model Applied to the Methyl Radical in Lithium
   Acetate Dihydrate Using Single Data, L. Kevan, P. A. Narayana, K. Toriyama,
   and M. Iwasaki, J. Chem. Phys., 70, 5006 (1979).

   A new general matrix ENDOR lineshape model is tested against

   ENDOR data on the methyl radical in γ-irradiated lithium acetate

   dihydrate. All parameters in the lineshape model are determined

   or narrowly limited by experiment. These include the dipolar

   tensors of all protons within 5 $\overset{o}{A}$ of the methyl radical, the micro-

   wave and radiofrequency magnetic fields, and the electronic and

   nuclear spin-lattice and spin-spin relaxation times. The theoretical

   simulations agree satisfactorily with the experimental lineshape,

   microwave magnetic field dependence, radiofrequency magnetic field

   dependence and angular variation of single crystal ENDOR line inten-

   sities. The effective nuclear spin-lattice relaxation time is $\sim$ 10

   ms at 77 K and seems to be dominated by some angularly independent

   nuclear relaxation mechanism. The angularly dependent electron-

   nuclear dipolar interaction is found to be of much less importance

   for the ENDOR response. It is noted that the angular variation of

ENDOR intensities is an important parameter to assess the
nuclear relaxation mechanisms that control the ENDOR re-
sponse. Data on cw and pulsed matrix ENDOR are compared
and found to be similar. It is also shown that a model
based on idealized lineshape theory for disordered systems
can satisfactorily reproduce matrix ENDOR lineshapes. Both
models allow calculation of the relative contributions from
angularly independent and dependent ENDOR responses.

9. Study of g-Anistropy Associated with Molecular Motion in the Triphenyl-
    methylperoxy Radical: An Environmental Probe, L. Kevan and S. Schlick,
    J. Phys. Chem., 83, 3424 (1979).

ESR spectra of triphenylmethylperoxy radical $\phi_3COO\cdot$ in γ-irradiated
polycrystalline triphenylacetic acid ϕ_3CCOOH were measured at 35 GHz
as a function of temperature from 80 K to 290 K. Multiple lines
were observed due entirely to g-anisotropy. Principal values of the
g-tensor at 80 K are 2.0320, 2.0092 and 2.0035. At 290 K an axial
g-tensor is observed with g≈2.0175 and 2.0128. At intermediate
temperatures new lines appeared in the specturm. All spectral
changes with temperature were reversible. The spectra were interpreted
with the modified Bloch equations for motional processes. All
salient features over the entire temperature range were well repro-
duced by a motional model involving 120° jumps of the peroxy group
about the C-O bond. The jump rates fit an Arrhenius plot and
give an activation energy of 9.2 kJ/mole. The possibility of
using the peroxy group as an environmental probe of its motional
freedom is discussed and several systems where this may be applicable
are given.

10. Interpretation of the ESR Spectrum from a Mobile Peroxide on a MgO Surface, S. Schlick and L. Kevan, J. Chem. Phys., 72, 784 (1980).

It is shown that the reported spectra of $(CO_2-O_2)^-$ on MgO at 77K and room temperature can be reinterpreted in terms of a single radical species undergoing intramolecular rotational motion of the O-O group. The "extra" lines in the spectrum at 77K arise from averaging of g-anisotropy and can be simulated by the modified Bloch equations. These results suggest that peroxy radical motion on surfaces can be used as an environmental probe that may be sensitive to local surface geometry.

11. Matrix ENDOR of the Protonated Carboxyllic Anion Radical in γ-Irradiated L-Alanine: Simulation Using a General Matrix ENDOR Lineshape Model and Single Crystal Data, L. Kevan, S. Schlick, K. Toriyama and M. Iwasaki, J. Phys. Chem., 84, 1950 (1980).

The matrix ENDOR line from $CH_3CH(\overset{+}{N}H_3)\overset{.}{C}OOH^-$ radical in γ-irradiated L-alanine powder at 77K was simulated using a generalized matrix ENDOR lineshape theory. The input includes hyperfine coupling constants for all protons in the proximity of the radical site as well as the pure dipolar interaction for more distant protons, microwave and radiofrequency magnetic field magnitudes and nuclear and electron spin lattice and spin-spin relaxation times. Simulated matrix ENDOR lines were tested against experimental lineshapes, linewidths and intensity of the ENDOR response as a function of the radiofrequency magnetic field. The simulated ENDOR response was found to be very sensitive to the value of the nuclear spin-lattice relaxation time and a value of 0.15s satisfactorily reproduces the experimental results.

The relevant conclusion from this study is that an angularly

independent nuclear relaxation mechanism dominates the ENDOR response.

12. Interpretation of Temperature Dependent ESR Spectra of Peroxy Polyethylene Radicals in Urea-Polyethylene Complex, S. Schlick, and L. Kevan, J. Am. Chem. Soc., 102, 4622 (1980).

Temperature dependent ESR spectra of peroxy polyethylene

radicals in urea-polyethylene complexes are successfully

simulated by the modified Bloch equations in terms of g-

anisotropy averaging of one radical. The motional model that

averages the g-tensor corresponds to 180° rotational jumps of

the O-O fragment around the C-O bond. An activation energy of

16.1 kJ/mole is derived for this motion. A comparison of peroxy

with nitroxide spin probes in polyethylene show that the peroxy

probe is more sensitive to the particular motional model that

controls the dynamics.

13. The Importance of Nuclear Spin Diffusion As An Angularly Independent Relaxation Mechanism Controlling the Matrix ENDOR Response of Radicals in Molecular Crystals, S. Schlick, L. Kevan, K. Toriyama and M. Iwasaki, J. Chem. Phys., 74, 282 (1981).

In the generalized matrix ENDOR lineshape model [P. A. Narayana

et al., J. Chem. Phys., 67, 1980 (1977)] the ENDOR intensity is

controlled by the nuclear spin lattice relaxation rate formulated

as an angularly dependent intrinsic bulk nuclear relaxation con-

tribution. Comparison of this model with single crystal data [L.

Kevan et al., J. Chem. Phys., 70, 5006 (1979)] showed that the

angularly independent relaxation rate must be more rapid than the

intrinsic bulk nuclear relaxation rate. Here we identify the

angularly independent relaxation rate with nuclear spin diffusion

and apply this interpretation quantitatively to data on methyl

radicals in lithium acetate dihydrate crystals and to the radiation

generated $CH_3CH(NH_3^+)$ $\dot{C}OOH^-$ radical in alanine at 77K.

14. Application of the Semicotinuum Potential Model to Deduce Localized Electron Trapping Sites in Single Crystals of D-Sorbitol, L. Kevan, S. Schlick, P. A. Narayana and Da Fei Feng, J. Chem. Phys., 75 1980 (1981).

The semicontinuum model of electron solvation (J. Am. Chem. Soc., 1976, 95, 1398) has been used to calculate the stability of the trapped electron in single crystals of D-Sorbitol at 4.2 K. Experimental ENDOR results suggest an envionment of two OH dipoles, with the protons at equal distances from the electron. The geometry of the most probable site in a lattice undistorted by irradiation result in a unbound electron state. This arises because the dominant term in the total energy is the dipole-dipole interaction which is attractive for that geometry. If the oxygen atoms remain fixed at crystal lattice positions but the protons are allowed to rearrange so as to point towards the electron, a minimum in the total energy is obtained, but the electron-proton distance is much shorter than the experimental value. However, good agreement with experiment is obtained for configurations of two or four OH dipoles pointing towards the trapped electron when lattice rearrangement is allowed. These calculations suggest that dipole rearrangement occurs during electron trapping in single crystals even at 4.2K.

15. Study of γ-Irradiated Lithographic Polymers by Electron Spin Resonance and Electron Nuclear Double Resonance, S. Schlick and L. Kevan, J. Appl. Poly. Sci., 27, 319 (1981).

The room temperature gamma irradiation degradation of the lithographic polymers, poly(methylmethacrylate) (PMMA), poly(methyl-

α-chloroacrylate) (PMCA), poly(methyl-α-fluoroacrylate) (PMFA) and poly(methylacrylonitrile) (PMCN), have been studied by electron spin resonance and electron nuclear double resonance (ENDOR) to assess their molecular degradation processes of relevance to electron beam lithography. Two classes of radicals are found, chain radicals and chain scission radicals. PMMA and PMCA mainly form chain scission radicals consistent with degradation while for PMCN the resolution is poorer and this is only probable. PMFA forms mainly chain radicals consistent with predominant crosslinking. The total radical yield is greatest in PMCA and PMCN. ENDOR is used to assess the compactness of the radiation degradation region for PMMA and PMCA and hence the potential resolution of the resist; this appears to be about the same for these methacrylate polymers.

16. Peroxy Radical Probe For Motion In Polytetrafluorethylene Chains, D. Suryanarayana and L. Kevan, J. Am. Chem. Soc., 104, 668 (1982).

The temperature dependences in the Q-band electron spin resonance (ESR) spectra of mid-chain and end-chain peroxy radicals in γ-irradiated polytetrafluoroehylene are investigated experimentally and theoretically using modified Bloch equations. Computer simulations are carried out for the following motional models; cubic jump, C-0 bond rotation (120° and 180° jumps), and chain axis rotation (90° and 120° jumps). For the mid-chain peroxy radical $[-CF_2CF(OO^{\cdot})-CF_2-]$, the partial g-averaging in the ESR spectra could be fit well by chain axis rotation with 90° jumps, whereas the complete g-averaging observed at room temperature for the end-chain peroxy radical $[-CF_2-CF_2-CF_2(OO^{\cdot})]$ could be fit using a cubic jump model. An activation energy of 18.4 kJ/mol was found for the

end-chain peroxy radical motion.

17. Peroxy Spin Probe Studies of Motion In Methacrylate Copolymers And In Polypropylene Chains, D. Suryanarayana and Larry Kevan, J. Phys. Chem. 86, 0000 (1982).

Motional effects in methacrylate polymers, including poly

(methylmethacrylate), poly(methyl-α-fluoroacrylate) and

poly(methylacrylonitrile) and also in polypropylene (isotactic)

have been investigated using peroxy radicals as spin probes. The

ESR spectra of the polymer peroxy radicals were studied as a

function of temperature from 77 to 370 K. The electron spin

reasonance spectra measured at both 9 and 35GHz revealed minor

changes in the spectral line shapes. However, reversible g

shifts in the $g_{//}$ component of the polycrystalline ESR spectra

was observed over the entire temperature range. This g- shift

has been attributed to the presence of motion in these polymers.

Various motional models including chain axis rotation with 90° or

120° jumps, C-O bond rotation with 180° or 120° jumps, and a cubic

jump process were considered. The experimental variation in the

spectra were best fit with the C-O bond rotational model with the

0-0 group undergoing two successive 180° jumps for a COO angle of

104°. It appears that chain axis motion is minimal for these poly-

mers due to steric hindrance of the side groups.

18. Peroxy Spin Probe Studies of Motion in Poly(vinylidene fluoride), D. Sur-yanarayana and Larry Kevan, J. Am. Chem. Soc., 104, 0000 (1982).

Motional effects in poly(vinylidene fluoride) have been invest-

igated using peroxy radicals as spin probes to contrast with previous

studies of peroxy radical motion in polytetrafluoroethylene and

in polyethylene. The predominant radical formed by radiolysis at

77 K is $-CF_2-CH_2$. In the presence of oxygen this radical readily

converts to the peroxy radical $-CF_2-CH_2-O-O$. The electron spin
resonance (ESR) spectrum of this peroxy radical was studied as a func-
tion of temperature from 77 to 360 K. The ESR spectrum measured
at both 9 and 35 GHz revealed changes in the spectral lineshapes
due to averaging of the g-anisotropy which is attributed to motion
in this polymer. Various motional models including polymer chain-
axis rotation, C-O bond rotation and a cubic jump process were con-
sidered. The experimental variation in the spectra are best fit
with a C-O bond rotation model with 180° jumps for a COO angle of
104° in a temperature range between 77 and 280K. However, above
280 K extra lines between the $g_{//}$ and $g_{\perp}$ regions of the spectra in-
dicate that a cubic jump motional process dominates. This is pre-
sumably related to the greater freedom of motion at the higher tem-
perature. The cubic jump motional process can be interpreted as a
helical twisting motion of the end of a polymer chain.

19. ESR Characterization of The Dynamical Properties of Urea - n - Alkane
Adducts Using Peroxy Spin Probes, D. Suryanaryana, W. Chamulitrat and
Larry Kevan, J. Phys. Chem. 86, 0000 (1982).

The motional effects in urea adducts of n- alkanes, of chain size
$C_{12}H_{26}$ to $C_{24}H_{50}$, have been investigated using peroxy spin probes
employing electron spin resonance (ESR). Temperature variations in
the ESR spectra of the respective peroxy radicals of urea - n -
alkanes were measured in the temperature range from 77 to 300 K. The
ESR spectra at low temperatures (~100K) reveal an antisotropic g-
tensor, $g_{//}$ = 2.037 and $g_{\perp}$ = 2.005, whereas at higher temperatures (~200K),
the g-tensor is averaged to a new set of values, $g_{//}^r$ = 2.002 and $g_{\perp}^r$ =
2.021. The isotropic g value is constant for the entire temperature
range. At intermediate temperatures the ESR spectra reveal "extra
features between the $g_{//}$ and $g_{\perp}$ regions which are characteristic of

peroxy radical motional effects. The spectral dependence with temperature has been successfully simulated using a chain-axis rotational model with 120° jumps for the entire temperature range employing the method of modified Bloch equations. The peroxy motion in urea - n - alkane adducts gives the following activation energies for the three-fold barrier: $E = 6.8$ kJ/mol for urea - n- $C_{12}H_{26}$ and $E_a=10.4$ kJ/mol for urea - n - $C_{20}H_{42}$. These values show the effect of chain length on the freedom of motion.

20. Study of Motional Effects In Poly(vinyl Alcohol) Chains by Analysis of Temperature Dependent Alkyl Radical ESR Spectra, D. Suryanaryana and Larry Kevan, J. Phys. Chem., 86, 000 (1982).

Temperature dependent electron spin resonance spectra of the $-CH_2-\overset{\cdot}{C}OH-CH_2-$ radical in γ-irradiated poly(vinyl Alcohol) powder at 9.2 GHz have been measured between 298 and 385 K. The spectral changes have been successfully simulated by the modified Bloch equations using a two jump model with interconversion between axial and equatorial beta hyperfine splittings.

3. Scientific Talks Presented

Army - T39 Application of Electron Spin Echoes and ESR Second Moment Analysis to the Determination of Matrix Structure Around Trapped Radicals in Disordered Systems, L. Kevan, P. A. Narayana, S. Schlick, M. K. Bowman, B. L. Bales and R. N. Schwartz, Twelfth International Symposium On Free Radicals, Laguana Beach, California, January 4-9, 1976.

Army - T40 Future Research Trends on Electrons In Condensed Media, L. Kevan, Symposium on Radicals and Electrons in Condensed Media, Caracas, Venezuela, January 26-31, 1976. Invited Lecture.

Army - T41 Electron Solvation Mechanisms, L. Kevan, Chemistry Seminar, Northern Michigan University, Marquette, Michigan, February 11, 1976.

Army - T42 Matrix ENDOR Studies of the Orientation of Amine Molecules Around Trapped Electrons in γ-Irradiated Amine Glasses, F. Q. H. Ngo, S. Noda and L. Kevan, Fourth Symposium on Radiation Chemistry, Keszthely, Hungary, June 1-6, 1976.

Army - T43 Solvated Electron Structure, L. Kevan, Seminar, Technical University, Todz, Poland, June 7, 1976.

Army - T44 Solvated Electron Structure, L. Kevan, Invited Lecture, Polish Chemical Society, Warsaw, Poland, June 9, 1976.

Army - T45 Geometrical Structure of Solvated Electrons, L. Kevan, Invited Lecturer, Annual Meeting of the Japanese Society of Radiation Chemistry, Kyoto, Japan, October 10-12, 1976.

Army - T46 Application of Electron Spin Resonance to Radiation Chemistry I, Invited Lecture Series, L. Kevan, Nagoya University, Japan October 19, 1976.

Army - T47 Application of Electon Spin Resonance to Radiation Chemistry II, Invited Lecture Series, L. Kevan, Nagoya University, Japan October 22, 1976.

Army - T48 Application of Electron Spin Resonance to Radiation Chemistry III, Invited Lecture Series, L. Kevan, Nagoya University, Japan October 26, 1976.

Army - T49 Localization and Solvation of Electrons in Condensed Media, L. Kevan, Invited Lecture Series, L. Kevan, Nagoya University, Japan October 26, 1976.

Army - T50 Localization and Solvation of Electrons in Condensed Media, L. Kevan Japan, Atomic Energy Research Establishment, Takasaki, Japan, October 27, 1976.

Army - T51   Localization and Solvation of Electrons in Condensed Media, L. Kevan, Seminar, University of Tokyo, Japan, October 28, 1976.

Army - T52   Localization and Solvation of Electrons in Condensed Media, L. Kevan, Radiation Center of Osaka Prefecture, Japan, November 30, 1976.

Army - T53   Application of Electron Spin Resonance to Radiation Chemistry, Lecture Series, L. Kevan, Hokkaido University, Sapporo, Japan, January 21, 1977.

Army - T54   Electron-Solvent Interactions, Invited Lecture Series of 12 lectures, L. Kevan, University of Paris-Sud, Orsay, France, Mary 7 - May 13, 1977.

Army - T55   Localization and Solvation of Electrons in Condensed Media, L. Kevan, Center for Wave Mechanics, C.N.R.S., Paris, France, March 31, 1977.

Army - T56   Known and Unknown Characteristics of Solvated Electrons, L. Kevan Seminar, University of Paris-Sud, Orsay, France, May 3, 1977.

Army - T57   An Improved Lineshape Model for the Matrix ENDOR Response in Disordered Systems, P. A. Narayana, M.K. Bowman, D. Becker, L, Kevan and R.N. Schwartz, VI International Symposium on Magnetic Resonance Banff, Canada, May 21-27, 1977.

Army - T58   Applications of ESR to Chemistry, Seminar, L. Kevan, University of Illinois at Chicago Circle, Chicago, Illinois, February 9, 1978.

Army - T59   Applications of ESR to Chemistry, Seminar, L. Kevan, Illinois State University, Normal, Illinois, February 10, 1978.

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